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CENTRAL INTELLIGENCE AGENCY

INFORMATION FROM
FOREIGN DOCUMENTS OR RADIO BROADCASTS

REPORT
CD NO.

50X1-HUM

COUNTRY	USSR	DATE OF INFORMATION	1947
SUBJECT	Scientific - Electronics		
HOW PUBLISHED	Monthly periodicaly	DATE DIST.	10 Jun 1949
WHERE PUBLISHED	Moscow	NO. OF PAGES	11
DATE PUBLISHED	Dec 1947		
LANGUAGE	Russian	SUPPLEMENT TO REPORT NO.	

THIS IS UNEVALUATED INFORMATION

SOURCE Uspekhi Fizicheskikh Nauk, Vol XXXIII, No 4, 1947. (FDB Per Abs 53T24 -- Translation requested.)

THIRTY YEARS OF SOVIET ELECTRONICS

S. Yu. Luk'yanov

In 1913 A.F. IOFFE studied the elementary photo-effect and showed the quantum nature of interchange between matter and radiation

A. Photoelectricity

In 19~~13~~24, ~~A.F.~~ P.I. Lukirskiy studied the photoeffect with crystals and, while working on X rays, developed a new method of a spherical condenser which was used by Lukirskiy and Prilezhayev in work, beginning in 1926, on photoelectric effects at metallic surfaces. In this work, the measurement of the energy of the photoelectrons and the work function was made by the method of retarding potentials. The application of the spherical condenser transformed the method of retarding potentials into one of the most accurate and reliable methods of determining the work function. The motion of photoelectrons in the field of a spherical condenser can be fully calculated beforehand from the geometrical dimensions of the apparatus; the maximum energy of the photoelectrons can be determined with a high degree of accuracy and the possible causes of errors can be determined or excluded.

In addition to the invention of this valuable method of investigating photoeffects, the great significance of the work of Lukirskiy and Prilezhayev lies in the fact that it provided a strict quantitative verification of Einstein's photoelectric equation. The correctness of this equation was verified to a high degree of accuracy. At the same time the numerical value of Planck's constant was determined with great accuracy and immediately attempts were made to find experimentally, by the photoelectric method, the energy distribution of electrons in metals.

Some years later there appeared the theoretical work of I. Ye. Tamm, in which a theory of the external photoeffect for the case of a clean metallic surface is developed by the method of wave mechanics. Discussing the question of the relation of the electrons to the crystalline lattice and the conditions under which the absorption of quanta by an electron of the metal did not produce a violation of the law of conservation of impulses, Tamm arrived at important conclusions concerning the presence of dual forms of the external photoeffect;

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of "surface" and of "volume" origin. The "surface" photoeffect is connected with sudden change of potential energy at the boundary of the metal, and the "volume" effect with the potential "relief" inside the metal (periodical field of the ions in the lattice). Tamm's theory served not only to clarify the causes of the appearance of selective maxima on the curves for the spectral distribution of photocurrent in pure metals in a number of cases, but also, shortly afterwards, drew attention to other cases of electronic emission at metallic surfaces.

The mechanism of selective photoeffect in the case of a complex surface was discussed in the works of Lukirskiy and Ryzhanov, while the interpretation of spectral selectivity for pure metals, arrived at from the optical constants of these metals, was given for a number of cases by Lukirskiy and Khurgin. This latter work was connected with the general series of studies carried out by AIVS on optics and on photoeffects for alkaline metals, and is one of the most important works in this field.

In later years, in the field of photoelectricity, as well as in the field of thermionics, the attention of physicists was concentrated not on the study of properties of pure metals, but on research on complex photocathodes of various types. From the invention of the caesium-oxide photocathode in 1930 until 1937, this was the main subject of the majority of the work on photoeffects. In the USSR the properties of this cathode, which was so important for technology, were studied intensely, its technology was worked out and its anomalous properties and the mechanism of its action were investigated.

In this connection, the outstanding study was the one conducted by Stalin Prize-Winner Timofeyev and his colleagues; from their laboratory came the first Soviet photoelement of high sensitivity with a caesium-oxide cathode. Timofeyev and Pyatnitskiy first began the study of the energy distribution of the photoelectrons, which was essential for understanding the mechanism of the action of this photocathode. Later Kushnir and his colleagues successfully continued the study of both this and other complex cathodes. Khlebnikov, together with Sinitsyn and Saytsev, studied the properties and technology of various modifications of the caesium-oxide cathode and investigated its spectral characteristics, fatigue, and the distribution of sensitivity on the surface. Finally, in 1944, the work of Morozov and Butslov appeared, which was rich in experimental material. In this work the connection of the photoelectric and optical properties of the cathode with the thickness of the semiconducting layer was observed. The experimental data obtained in this work made possible a new appraisal of the complexities of the action of the caesium-oxide photocathode and, in particular, refuted various constructions developed by de Bur.

In 1936, the antimony-caesium photocathode was discovered. A year later the first Soviet work on the subject appeared, in which Lukirskiy and Lusheva described the properties of photoelements with cathodes of this type. At this time, the technology for this cathode was still undeveloped, the mechanism of its action was unknown, and its properties had been studied very little. Even in this first work, surprising and ingenious explanations of a number of the newly discovered anomalous properties of the photoelement with the new cathodes were given. In particular, the absence of saturation with photoelements in vacuo is explained by the great longitudinal resistance of the cathode and the appearance on it, before illumination, of a fall of potential. Consequently, a "sliding" photocurrent appears, increasing at the expense of secondary emission: this current increases with the voltage and is superposed on the initial current at the cathode. Later, when the value of the new cathode became clear to physicists and when its remarkable properties (great photosensitivity, stability in operation, simplicity of manufacture) aroused widespread interest, a large number of works appeared on antimony-caesium cathodes; the overwhelming majority of these were from Soviet scientists. The first publication in the US concerning the new photoelements appeared in 1941, and there is no doubt that not only have antimony-caesium photoelements been more fully studied in Russia than in England or America, but also that its applications in technology were made earlier and are more widespread. It is possible to mention only some of the many questions concerning this work in this article.

In 1939, Prilezhayev, studied the properties of antimony-caesium cathodes in equilibrium with caesium vapour through extensive experiments carried out by the method of the spherical condenser. This work of Prilezhayev, which is closely allied to the famous researches of Langmuir concerning the absorption of atoms on metallic surfaces, contributed much to the understanding of the process of activation of the cathode and the mechanism of its operation.

In the interesting and fastidious studies of Vekshinsky, carried out in the laboratory of the "Svetlana" factory in 1940, the microstructure of the antimony-caesium cathode was studied (earlier work had been carried out on the caesium-oxide cathode). In the study of the photoeffect of the surface of various elements, Vekshinskiy applied his own method for the automatic recording of photo currents very successfully. He later applied the results obtained by his method in his studies on the process of crystallization of thin metallic films of antimony successfully in metallographic studies on alloys of various elements. For the latter, Vekshinskiy was awarded a Stalin Prize in 1946. Thus, wide applications in completely different branches of technology developed from photoelectric studies on the methods of obtaining and analyzing thin metallic films.

In 1939, S. Yu. Luk'yanov determined the quantum sensitivity of antimony-caesium cathodes by a new method, the sensitivity reaches the enormous value of approximately 1/4 electron per quantum at points of spectral maximum of sensitivity of the cathode. This development makes it possible to regard the new cathodes as very sensitive indicators for radiant energy of a given wave-length.

Later Khlebnikov and Melamid showed that the antimony-caesium photo-cathode is also very sensitive in the ultraviolet region of the spectrum. They designed photoelements with thin-walled windows and successfully solved the problem of creating sensitive apparatus for recording ultraviolet radiation.

For research into the spectral characteristics of antimony-caesium cathodes, S. Yu. Luk'yanov used the well-known Fowler-Dewbridge method for determining the work function in the case of a cathode of a semiconducting nature.

A number of studies on antimony-caesium cathodes have been carried out in the Institute of Physics in Kiev and in the All-Union Electrical Institute in Moscow. In particular, Morgulis and Dyatlovitskaya have investigated the emissive properties of these cathodes in detail, observing the effect of temperature and the electrical conductivity of the layer on the characteristics of antimony-caesium photo elements. The work of the Kiev physicists in this direction has continued in recent years. Particularly promising is the recent work of Morgulis and Borzyak, in which the connection between the optical constants of an antimony-caesium cathode and its photoelectric properties was studied. The results of these experiments are of interest not only in the field of photoeffects, but also for the physics of semiconductors, since data concerning the behavior of electrons which are excited by light in a semi-conducting medium can be obtained from them.

An interesting physical study on the antimony-caesium cathode was published in 1947 by Brezhnev, who studied the effect of an electric field on the photoelectric emission of this cathode (Shottky photoelectric effect). In this work Brezhnev first investigated for a type of antimony-caesium cathode, the auto-electron emission for a semiconducting surface. Many efforts to introduce the new cathode into various fields of technology have been made by Khlebnikov who, together with Zaytsev and Sinitsyn, has studied the luminous and electrical characteristics of antimony-caesium photo elements.

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In concluding this survey of physical studies on photoeffects, we should mention the presentation of a new point of view concerning the mechanism of emission from complex cathodes by Khlebnikov in 1945. Connecting the photoeffect from such surfaces with a power model of a semiconductor, Khlebnikov strongly criticized many points of de Bur's theory, in which the role of atoms of alkali metals, absorbed on the surface of complex cathodes is undoubtedly overestimated. With its very logical approach, Khlebnikov's presentation can make a positive contribution to the search for new photocathodes and to the investigation of existing cathodes. Among the work on special technical applications of photoeffect, we should mention Braude's work in 1937, in which a new and very ingenious apparatus designed for the television transmission of motion pictures was described. The essential part of this apparatus consists of a photosensitive metallic wire, on which is projected a line of frame to be transmitted. By setting up an electric field along the wire which moves with the speed of exposure, and collecting the photoelectrons emitted by the filament, we obtain in the collector circuit a photo current, the speed of growth of which will be proportional to the light-signal from the element of the transmitted picture. Braude's television system is a completely original solution of the problem and, as demonstrated by the Leningrad Television Center, is very suitable for the transmission of cinefilms.

B. Secondary Electron Emission

In 1920, P. I. Lukirskiy and N. N. Semenov conducted the first studies in the USSR on secondary electron emission; they measured the coefficient of secondary emission for mercury and studied its dependence on the energy of primary electrons. Because of the limitations of vacuum technique at that time their numerical data is not considered accurate by present standards; nevertheless, their qualitative explanation of the observed dependence is completely valid.

L. A. Kubetskiy's invention of the multistage electron-multiplier photo tube in 1934 (this invention was duplicated shortly afterwards by Zvorykin in America and by Weiss and others in Germany) aroused increased interest in secondary emission and in later years a valuable stream of work has appeared on the physics and technology of secondary-electron emission. In these works the mechanism of the phenomena for the simplest case of pure metallic surfaces was studied, principles necessary for understanding the processes occurring in complex cathodes were established, new surfaces having large coefficients of secondary emission were described, and numerous more efficient designs of electron-multiplier phototubes were suggested.

In 1938-1939, Vyatskin began the formation of a strict quantum-mechanics theory of the phenomena for the case of a pure metal. After criticizing strongly the theory suggested by Frelich, Vyatskin treated the whole problem of a pure surface in the light of the Sommerfeld model of a metal. The theory in this form was of established value and interest for analyzing experimental data on pure alkali metals in a field of low-energy primary electrons; however, this theory cannot accurately describe the phenomena of high-energy electrons for the case of ionization in connection with atomic ions. Later, in 1944, Vyatskin substantially developed and extended his theory. In his new work, secondary electron emission is regarded as a phenomenon dependent on the complexity of the surface and on two-volume effects caused by the "free" electrons in the lattice and the atomic electrons. The volume effect for "free" electrons determines the precise structure of the energy-distribution function for secondary electrons, while the surface effect gives the basic form of the energy-distribution function. Both volume effects combined provide approximately 10 - 20 percent of the secondary emission. Also of interest for the theory of electron emission from metals is Vyatskin's theory, developed in the same work in 1944, concerning the absorption of electrons (primary and secondary) inside the metal because of interaction with the electrons of the metal.

In the theoretical works of Kadyshevich, secondary emission is regarded as a volume effect, like a process of ionization, proceeding in the mass of the secondary cathode. The ionization theory agrees with experimental values for dependence of the coefficient of secondary emission on the energy of the electrons and later applications to semiconducting surfaces explained the causes for the great increase in this coefficient for complex cathodes. Actually the value for this increase agrees only very approximately with the theory, but it must be remembered that, previously, no satisfactory explanation existed concerning the behavior of slow electrons produced during emission in the mass of the cathode, particularly when the internal structure was complex, as in the case of present-day emitters.

Extensive experimental research on this problem has been carried out. In 1936, the work of Afanasyeva and Timofeyev, which preceded the well-known work of de Bur, made clear the important question of the increase in the coefficient of secondary emission for pure alkali metals, and it was shown that for the latter, increase in σ was less than for other pure metals. Afanasyeva and Timofeyev applied a new experimental method for the study of secondary emission, the deposition of layers of atoms of another metal of gradually increasing thickness on metallic backing, which proved very useful for studying the mechanism of the phenomena and was widely used afterwards.

The work of Khlebnikov and his colleagues clarified the part played by absorbed gases. Later, the accurate experiments of Morozov (1941), not only gave a reliable and accurate value for the coefficient of secondary emission for many pure metals, but also confirmed the results of Kushnir and his colleagues concerning the dependence of secondary emission of pure metals on temperature within wide limits. In the same work, the effect of the transition of the metal through the melting point on secondary emission was studied.

In 1937, S. Yu Luk'yanov and Bernatovich made a very accurate study of the dependence of the coefficient of secondary emission on the angle of incidence of the primary electrons. The increase of secondary emission for obliquely incident primary electrons was established both for pure metallic surfaces and for complex caesium-oxide emitters. This problem was later studied in detail by Kushnir and his colleagues in a number of works (1941-1946) in which they studied the effect of the angle of incidence of the electron beam on the total secondary emission, and also conducted difficult experimental research on the effect of the angle of incidence upon the energy-distribution function for secondary electrons. The dependence of the distribution function for secondary electrons on the angle of departure was also studied. In Kushnir's laboratory the study of the dependence of secondary emission upon the angle of incidence of the primary beam is important for the design of electron multiplier phototubes and the explanation of the experimental data obtained is important for understanding the mechanism of the phenomena. In particular, some ideas developed by Luk'yanov and Bernatovich in thier work, (see above), were used for the development of the ionization theory of secondary emission.

Secondary emission from pure semiconductors was first studied in the works of Afanasyeva, Timofeyev and Frimer and for dielectrics by Vudynskiy as well as by Kosman and his colleagues in a particularly outstanding work, in which new methods were utilized.

The study of efficient emitters, i.e. surfaces with large coefficients of secondary emission, is closely connected with the so-called Malter effect. This term is applied to the superposition, in a number of cases, of autoelectronic emission on the real secondary emission from a surface. It is often very difficult to seperate the results of these two effects, real secondary emission and the Malter effect. This problem is of great importance both theoretically, from the standpoint of explaining the mechanism of secondary emission from nonmetallic surfaces and, practically, because efficient emitters of secondary electrons are found among these types of surfaces. Some investigators, headed by Timofeyev and his colleagues, believe that, in general, the substantial coefficients of secondary emission of semiconducting emitters ($\sigma \rightarrow 2/3$) already indicate the presence of the Malter effect in a special form, while at the same time, others (Morgulis, Zernov, Khlebnikov) believe that real secondary emission can give values of σ amounting to 10 - 12.

Consequently, at present, there are a whole series of works by Soviet physicists dealing with studies of emitters of the semiconducting type. In the course of this work, the energy-distribution of emitted electrons for a number of surfaces has been explained and two groups of electrons, real secondary electrons and "autoelectrons" have been discovered, in the case of typical Malter emitters. In addition, measurements have been made of the fall of potential in a layer of a semiconductor giving the greatest value for σ, and the existence of intermittent transitions from emission of the usual type to Malter emission with changes of thickness of the semiconductor (Zernov) has been demonstrated experimentally. The temperature dependence upon the density of the primary current, the speed of primary electrons, etc. has been determined for many efficient emitters.

All these studies, in addition to providing data of purely physical interest, have also placed at our disposal a valuable "arsenal" of secondary-emitting surfaces, possessing high coefficients of secondary emission, reliable in operation, and capable of considerable loading. Of particular interest in connection is the magnesium oxide emitter, developed by Aranovich in Timofeyev's laboratory, having a value of σ of the order of 30-50 (instead of the usual value in technology of 8-10) withstanding temperatures up to 1,000 degrees centigrade. Mention should also be made of the copper-sulfur-caesium emitter, developed in Kubetskiy's laboratory, which has proved very suitable for application in a photomultiplying magnetron with the cathode on the glass envelope.

The pioneer in the technological application of secondary emission has been L. A. Kubetskiy. He not only described an actual design for a multistage amplifier, but in 1934 he built a working model of the apparatus. In recent years Kubetskiy, Vekshinskiy, and Timofeyev have created numerous, very sensitive variants of photomultipliers and electron tubes using secondary emission in the laboratories of the "Svetlana," factory in the All-Union Electrical Institute and in the Institute of Telemechanics. The main obstacle to the development of these tubes in recent years has been the lack of sufficiently efficient and heat-resisting cathodes, this difficulty can be considered surmounted.

Original expectations of a revolution in amplification technology, to be brought about by the introduction of electron multiplier phototubes have proved to be overoptimistic. At the present time, in the competition between the two systems, vacumm-tube amplifiers and electron multipliers, phototubes, victory seems to lie with the older system, but it must be remembered that vacuum-tube circuits have already been very fully developed. Multipliers suffer from a number of shortcomings; they are not standardized to the same extent as vacuum tubes and are less stable. Their main advantage lies in great amplification of weak h.f. signals, for example in television, because the signal-to-noise ratio is higher than it is in vacuum-tube circuits. Application to talking films is possible, but the question as to which is the most efficient system (vacuum-tube amplifier, photomultiplier, or a thallium-sulfur photo element with a blocking layer) still remains unanswered.

C. <u>Thermo-Electronic Emission</u>

During 1911-1913, Langmuir and Childs solved the problem of calculating the increase in electron current in a vacuum in the presence of a space charge, assuming absence of initial velocity, for the plane and cylindrical cases (Langmuir's 3/2 Law). For the cylindrical case the solution was, however, only approximate and in 1923, an exact solution was obtained simultaneously and independently by Boguslavskiy in the USSR and by Langmuir and Blodgett in the US. Boguslavskiy's work contained a full and strict treatment of the problem, but as it was published after the author's death, in 1924, in a journal with limited circulation, it has, unfortunately, remained unknown to the majority of later investigators.

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Another noteworthy early work in this field was that of Pavlov and others, published in 1923, dealing with research on the movement of electrons between two plane grids. In this work the presence of initial speeds (assumed to be constant) for the electrons was studied and a certain inexactness was pointed out in the solution, i.e., for the given conditions, the value of the current in the apparatus was not fully determined by the value of the potential on the electrodes. This work was also forgotten and Pavlov's work was duplicated, considerably later, in the works of foreign investigators.

The first Soviet work on radio tubes was carried out in the years 1918-1919, when Bonch-Bruyevich and Ostroumov in the Nizhegorod radio laboratory laid the foundations of the Soviet electrovacuum industry and carried out the first experimental research on electronic phenomena in tubes.

Experimental research by Soviet physicists on thermoelectronic emission from various surfaces appeared in later years. The main body of this work was continuously connected with the physics laboratory of "Svetlana" factory directed by Vekshinskiy and Lukirskiy during these years which played a unique role in creating Soviet electrovacuum apparatus. Among these works the fine experiments of Vekshinskiy, Lukirskiy, Gozina, and Tsareva (1930) concerning the effect of layers of "foreign" atoms absorbed on the surface of the metal on thermoelectronic emission should be mentioned. These experiments, and also the studies of Ptitsyn, Berdennikova, Morgulis, and his colleagues, Ravdel, Anselman and Dozlyakovskiy, were the starting point for extensive work on the study of complex incandescent cathodes of various types, and for the development and refinement of the technology of the thoriated and carbon cathodes, and later the oxide and barium cathodes.

Much valuable work was done in the field of electrovacuum technology by Ivanov, a recently deceased engineer and physicist of the "Svetlana" factory. A leading part in creating Soviet radio tubes has been played by Vekshinskiy, Shaposhnikov, and Zusmanovskiy. The latter, together with Katsman and Moshkovich, was awarded a 1941 Stalin prize for the invention of a low-voltage amplifier.

Among the studies of a purely physical character, we should mention the works of Butkevich, Morgulis and Dyatlovitskiy, who studied electron emission from a thoriated tungsten filament. Dobretsov and Morozov investigated the evaporation of barium on tungsten and determined the heat of absorption of the atoms of Ba, and also the time of absorption of Ba with various coatings and temperatures.

The Shottky effect for thermoelectronic emission was studied in the works of Dobretsov and Morgulis. In one of the later works (1941), Dobretsov undertook the exact determination of the change in the work function under the influence of an external electric field, using a thermal method. He made careful measurements of the latent heat of evaporation of electrons with various external fields and showed that these measurements of the latent heat of evaporation agreed with the measurements for the work function, as given by Shottkiy's theory.

Interesting studies on the investigation of the behavior of oxide cathodes under impulse conditions were recently (1944-46) published by Andrianov, Morgulis, Kalashnikov and others. The detailed explanation of this problem has great significance for the solution of many problems of present-day radio technology.

The complete description of Soviet work on radio tubes belongs to the field of radiotechnology and cannot be given here, but we shall deal with one series of studies in which Soviet scientists have contributed much that is new and original.

The development of microwave technology, in connection with the successful development of a magnetron oscillator, has aroused increasing interest in the explanation of magnetron operation. In a number of articles, the publication of which began in 1934-1935, Grinberg, together with Lukoshkov and other workers of the "Svetlana" factory, calculated the fields in a slotted magnetron, and, using

Grinberg's graphoanalytical method, were able to plot the electron trajectories in these fields. Consequently, it was possible to explain fully the causes of the negative resistance of the magnetron, disproving the earlier inaccurate theory of this phenomena. Also of considerable importance to radio technology is the explaination of problems concerning the nonslotted magnetron, the calculation of the fields, the determination of the dependence of the current-strength on the magnetic field, etc. For the "spherical" magnetron, this was accomplished by Braude in 1936; for the cylindrical magnetron, the full solution was first given in 1938 in a study by Grinberg and Volkenshteyn, which states, in particular, the formulas for determining the wave lengths of the transient oscillations and their dependence upon the dimensions and upon the applied fields.

Another interesting study in microwave technology concerns the theory of the passage of an electron current near the limits of its space charge, through a plane diode of such high frequency applied voltage that the period of the high-frequency field is comparable to the time of flight of the electrons through the apparatus. In 1935, Grinberg, in addition to new investigations of the plane case, first gave the full solution for a cylindrical diode. In the work of Grinberg and Blizhyuk in 1938, the corresponding calculations were given for determining the values of the complex impedance of a cylindrical diode at high frequency. In addition, Grinberg investigated in detail the initial stages of the passage of an electron current through a diode when an impulse-voltage was switched on to the anode (motion of the "electron front" and the accompanying formation of a space charge).

Mention has been made above of the importance of theoretical work in investigating the magnetron. Experimental development and research on magnetrons has been carried out successfully for a long period by GREKHOVA, apart from that in "Svetlana" factory, ~~first in Moscow~~ and later in the Gorky Physicotechnical Institute. She has also carried out valuable work on electron-beam tubes. In addition, wide experimental research on the magnetron has been done by Slutskin, who has also made various theoretical calculation on the sam· subject.

D. Surface Ionization and Ionic Emission

The phenomenon of surface ionization was observed by Langmuir and Kingdon, in 1923-1934, for the case of the ionization of caesium atoms on the surface of incandescent tungsten. Then the well-known Langmuir-Sak formula was devised for the temperature dependence of this phenomenon. The subject matter of this research (caesium on tungsten) however, did not permit a thorough check of this formula to be made, since the atoms of caesium reached practically 100 percent ioni--tion over the whole temperature range convenient for the investigation. Therefore it was not until considerably later, in 1934, in the works of Dobretsov and Morgulis on the ionization of potassium, sodium, and barium on the surface of tungsten, molybdenum and tantalum, that the temperature dependence for ionic emission was first satisfactorily investigated and the applicability of the Langmuir-Sak formula was fully verified.

Particularly fine experiments were made by Dobretsov, who used the very thorough method of molecular beams. It should be emphasized that the interesting case of sodium on tungsten (the ionization potential for Na is greater than the work function for W!) had not previously been generally investigated. In 1934, Morgulis also studied the reverse phenomenon, the neutralization of ions of alkali metals on metallic surfaces.

Surface ionization on complex cathodes was first studied in Russia. In 1934, Dobretsov undertook the investigation of surface ionization for thoriated tungsten and subsequently he accurately analyzed all aspects of this phenomenon. The interest and significance of this work extends far beyond the study of the effect of surface ionization. The first experimental demonstration of the presence of "mottled structure" in complex cathodes occurred in the course [redacted] 50X1-HUM

of this work. Electron-optical research was carried out later and the well-known discussion of Langmuir, Kingdon, and Bekker concerning "Mottling of thorium on tungsten" in 1934 was of a purely hypothetical nature. In this way, surface ionization can be used as a new method for studying the structure of complex cathodes. It also successfully supplements thermoelectronic research on the portions of the cathode with the minimum work function, while surface ionization proceeds particularly readily on portions with maximum work function.

Later, in 1936, Dobretsov, as a result of discussions with Morgulis, showed that the effect of an electric field on surface ionization, over a wide range of field-strengths, produced a Shottky effect for ions. In 1937-1938, Dobretsov and Konozenko, Morgulis and Dyatlovitska first studied the effect of an electric field on surface ionization of thoriated tungsten ("the anomalous Shottky effect for ions"). Studies in this branch of the subject were first suggested by Soviet physicists, who later achieved complete explanations of the phenomena.

In 1937, Ionov, acting on a suggestion by Lukirskiy, began the study of surface ionization of atoms forming negative ions. In 1940, Dukelskiy and Ionov published a work detailing their investigation of the formation of negative halide ions during the reaction of alkali halide molecules with the surface of incandescent tungsten. These studies, continued latery by Ionov, undertook the verification of the applicability of the Langmuir-Sak formula to ionization of this type. The value of study along these lines includes the possibility of the direct measurement of electron affinities of various atoms, which is very difficult to determine by other methods. Similar studies have been carried on for a number of years in Tashkent, where the experiments, begun in 1935 by Starodubtsev in Lukirskiy's laboratory, on the surface ionization of alkali halide salts were continued. It was clearly shown that the study of the temperature characteristics and the absolute coefficients of this type of ionization provides a means of determining the heat of the reaction on the surface of the metal. Shupp and Arifov continued the study of positive ionization of salts and the negative ionization of halides on thoriated tungsten at the same place.

Work closely related to these questions has been conducted by Pavlov and Morozov (1935-1940) on the study of the ionic emission of various chemical compounds, and by Pavlov and Starodubtsev on the investigation of the reactions of slow and fact ions with metals and with films of semiconductors. The large amount of experimental material obtained from these experiments needs further development and systematization, since it could be developed into a new, original section of surface chemistry.

Quite recently (1946-1947), Dobretsov, Starodubtsev, and Timokhina observed a new type of surface ionization, the ionization of atoms of metals on thin films of oxides of the same metals. The observed phenomena do not fit into the framework of the usual theory and deserve further intensive study.

E. <u>Electron Diffraction</u>

In comparison with other fields of electronics, the Soviet works on electron diffraction are few in number, but many of them have proved vital for development in this field.

First, we should mention the work of Tartakovskiy, a pioneer in studies on electron diffraction, which he has carried on since 1927 in Leningrad and Tomsk. Interesting studies were conducted by Kolpinskiy in the Physics Institute of Leningrad State University on the study of polycrystalline thin films with orientated crystals, and by Kolpinskiy and Fok, who investigated, both theoretically and experimentally, electron diffraction from deformed crystals In the same place Alikhanyan and Kosman studied electron diffraction with "relativistic" electrons.

Lashkarev and his colleagues investigated the diffraction of slow electrons and demonstrated the dependence of the refractive index of the electron waves on the speed of the electrons. Lashkarev and Usyskin used electron diffraction to determine the space structure of the ammonium chloride molecule.

In addition to experimental work in this field, theoretical studies have been made by Tartakovskiy, Lashkarev, Kalashnikov and others.

F. Electron Optics

The problems of electron optics did not attract the attention of Soviet physicists until a much later date, since all the published work on this subject has appeared in the last 7-8 years. Nevertheless the work of Soviet scientists has substantially enriched this branch of electronics by theoretical research, new ideas, and original designs for electron-optics apparatus.

The importance that is attached to the artificial production of ions with great energies is well known in present-day nuclear physics. The best method for obtaining such ions is the cyclotron; however, the relativistic increase in mass of the particles during their acceleration effectively limits the possibilities of this remarkable instrument. For many years it seemed that the only way of reaching higher energies would be to increase the voltage, which would require a larger clearance between the poles and would increase the size of the powerful cyclotrons which were already quite massive. A completely new principle was introduced by Veksler in 1945, when he suggested the use of "auto-phasing," a method which he had discovered. It appeared that, by introducing slow variations of frequency, it was possible to effect a sudden increase in the limiting energy of the ions without changing the size of the cyclotron. His work was soon repeated in the US and, at the present time, the cyclotron with modulated frequency is one of the most perfected tools of applied nuclear physics.

Interesting work has also been conducted by Soviet physicists toward the solution of the problem of accelerating electrons. In 1939, long before Kerst's well-known work, Kelman, Korsunskiy, and Lang, in the Kharkov Physicotechnical Institute, designed a magnetic electron mirror and had begun work on its application to the construction of a "quadrutron," an apparatus for the repeated acceleration of electrons. Unfortunately, this work and the theoretical researches of Terletskiy (1941), who, independently of Kerst, re-examined the ideas of Videroe on the creation of an electronic transformer, were interrupted by World War II.

It was in Kharkov also that Korsunskiy, Kelman, and Petrov first suggested and realized experimentally the construction of a light-intensity β -spectrograph with a nonhomogeneous magnetic field, which was used to obtain aberration-free focusing of wide-angle (40 degrees) electron beams.

Of particular interest are the studies of Grinberg, published in 1942, on the general theory of focusing electrons in electrostatic and magnetic fields. The importance of this work lies in the fact that it gives some general laws for action of charged particles under the influence of electrical and magnetic forces and these laws determine the conditions for the focusing of electron and ion beams. Long ago, certain special cases of the movement of electrons in electrical and magnetic fields leading to focusing of the electron rays were observed which were analogous to the focusing of light rays by optical instruments. The analysis of these special cases was the task of theoretical electron optics and many varied and interesting practical applications resulted from this work. For the further development of this science, however, the substantial development of theoretical electron optics was an imperative necessity. The necessity for the expansion of the theoretical bases of electron optics had long been appreciated by workers in this field but, until the appearance of Grinberg's work, few advances had been made toward the solution of the general problems of electron focusing. The results obtained by Grinberg are the present foundations of electron optics, and today, theoretical work in this field is almost complete.

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Grinberg's solution of the problem was obtained by completely new methods which are of great interest from the standpoint of theoretical mechanics. In mechanics, the problem of the motion of a particle usually consists of defining a field of force and then investigating the motion in this field. By this method, the geometrical forms of the trajectories are known only when the calculations are completed. In Grinberg's work, however, the basic problem of dynamics was, so to speak, turned inside out. Because of the practical necessity of controlling, as required, the form of the electron trajectories, Grinberg set out to examine the possibility of determining the electrical or magnetic field required by a beam having a trajectory of a given form. This new approach to the problem was fully justified by its success, not only in explaining under what conditions the focusing of electron trajectories was possible, but also in providing formulas for determining the fields needed for beams of a given form.

In 1944, Artsimovich published an important theoretical work dealing with the observed electron-optical properties of emission systems. Sucy systems include all apparatus in which images of objects, which emit slow electrons are obtained: examples are the emission electron microscope, the television dissector, and the electron guns of Kinescopes. In spite of their great practical importance, the theory of such systems up to that time had only been developed in a very inadequate form. Artsimovich not only found an original method of solving the associated differential equations for the trajectories of the electron beams in these cases, but also produced a calculation for the resolving powers and main electron-optical abberations of those systems.

In recent years, electron optics, has been applied by Rik and Kormakova to the analysis of the trajectories of electron beams in electron multiplier phototubes. Electron-optical researches have been carried out for the incandescent cathodes by Morgulis and for antimony-caesium photocathodes by Brezhnev.

The most important item of the widespread work, carried out for several years in the State Optical Institute by A. A. Lebedev and his colleagues, was their creation of the first Russian-built specimens of electron microscopes. In 1947, Lebedev, Vertsner, and Zandin were awarded a Stalin Prize for this work.

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